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Workshop on

Harvesting Impacts on Bottomland Hardwood Forest Ecosystems

ABSTRACTS

Workshop on

Harvesting Impacts on Bottomland Hardwood Forest Ecosystems

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Delta Branch Experiment Station
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J. P. Shepard, National Council of the Paper Industry for Air & Stream Improvement
V. V. Burkett, National Biological Survey

AGENDA

Wednesday, May 18, 1994

7:30 - 8:15	Registration
8:15 - 8:30	**Welcome and Introduction.** J. A. Stanturf, U. S. Forest Service, Southern Hardwoods Laboratory.
	Moderator, V. V. Burkett, National Biological Survey
8:30 - 9:00	**Overview of the Resource--Today and Yesterday.** R. C. Kellison and M. Young, Hardwood Research Cooperative, North Carolina State University.
9:00 - 9:30	**Development and Ecology of Bottomland Hardwood Sites.** J. D. Hodges, Mississippi State University.
9:30 - 10:00	**Silvicultural Systems for Southern Bottomland Hardwood Forests.** J. S. Meadows and J. A. Stanturf, U. S. Forest Service, Southern Hardwoods Laboratory.
10:00 - 10:30	**Break**
10:30 - 11:00	**Spawning and Rearing of Fishes in Bottomland Hardwood Wetlands of the Southeastern United States.** K. J. Killgore, G. Miller, and J. J. Hoover, USACOE, Waterways Experiment Station and University of Mississippi.
11:00 - 11:30	**Harvesting Impacts on Soils and Nutrient Cycling.** W. H. McKee, Jr. and W. H. Conner, U. S. Forest Service, Wetlands Center, and Belle W. Baruch Forest Science Institute.
11:30 - 12:00	**Harvesting Systems.** B. J. Stokes and A. Schilling. U. S. Forest Service, Southern Forest Engineering Center and International Paper Company
12:00 - 1:00	**Lunch** (Catered)
	Moderator, T. C. Fristoe, Scott Paper Company
1:00 - 1:30	**Impacts on Landscape Diversity.** T. B. Wigley and T. Roberts, NCASI and Tennessee Tech University.
1:30 - 2:15	**Recovery Status of a Cypress-Tupelo Wetland Eight Years After Harvesting.** W. M. Aust, S. H. Schoenholtz, T. Zaebst and B. Szabo, Virginia Tech University and Mississippi State University
2:15 - 2:45	**Break**
2:45 - 3:30	**Influence of Harvesting on Water Quality, Hydrology, Denitrification, Decomposition, Amphibian Populations, Microbial Ecology, and Regeneration in Narrow Floodplains of Blackwater Streams in Southern Alabama.** B. G. Lockaby, R. H. Jones, R. G. Clawson, A. Griffin, S. Lloyd, F. C. Thornton, D. A. Brown and J. A. Stanturf. Auburn University, Tennessee Valley Authority, and U. S. Forest Service, Southern Hardwoods Laboratory.
3:30 - 4:15	**Timber Harvesting Impacts in a South Carolina Blackwater Swamp.** D. Perison, R. Lea and R. C. Kellison, International Paper Company and Hardwood Research Cooperative, North Carolina State University.

Thursday, May 19, 1994

8:00 - 8:15	**ANNOUNCEMENTS**
8:15 - 9:00	**INITIAL RESPONSES OF VEGETATION, WATER QUALITY, AND SOILS TO HARVESTING INTENSITY IN A TEXAS BOTTOMLAND HARDWOOD ECOSYSTEM.** M. G. Messina, S. H. Schoenholtz, M. W. Lowe, Ziyin Wang, D. K. Gunter and A. J. Londo. Texas A&M University and Mississippi State University.
9:00 - 9:45	**ROAD CONSTRUCTION AND HARVESTING IMPACTS ON FUNCTIONS OF A REDWATER FLOODPLAIN FOREST IN CENTRAL GEORGIA.** B. G. Lockaby, R. G. Clawson, K. M. Flynn, R. B. Rummer, B. J. Stokes, and J. A. Stanturf. Auburn University, U. S. Forest Service, Southern Forest Engineering Center and U. S. Forest Service, Southern Hardwoods Laboratory.
9:45 - 10:15	**COMPARISON OF PRODUCTIVITY VALUES ACROSS A FLOODING GRADIENT IN A SOUTH CAROLINA COASTAL PLAIN FOREST.** M. K. Burke and W. H. Conner. U. S. Forest Service, Wetlands Center and Belle W. Baruch Forest Science Institute.
10:15 - 10:45	**BREAK**
10:45 - 11:15	**FORESTED WETLAND PRODUCTIVITY: A STUDY OF REGIONAL PROCESSES.** W. H. Conner, B. D. Keeland and J. P. Megonigal. Belle W. Baruch Forest Science Institute, U. S. National Biological Survey and Duke University.
11:15 - 11:45	**BOTTOMLAND HARDWOOD FOREST MANAGEMENT AND INFORMATION NEEDS FOR WATERSHED PLANNING.** J. P. Shepard, NCASI.
11:45 - 1:00	**LUNCH** (Catered)
1:00 - 1:30	**WHERE DO WE GO FROM HERE? PROPOSAL FOR A REGIONWIDE STUDY OF ECOSYSTEM RESILIENCE ACROSS A PRODUCTIVITY GRADIENT.** J. A. Stanturf and B. G. Lockaby, U. S. Forest Service, Southern Hardwoods Laboratory and Auburn University.
1:30 - 3:30	**BREAK-OUT SESSIONS** Purpose of these sessions is to identify common results, good techniques, and outstanding research questions. Sessions will be organized around the following functions and processes: Regeneration Hydrology Nutrient Cycling Water Quality Biodiversity
3:30 - 4:30	**SESSION REPORTS**
4:30 - 5:00	**WRAP-UP**

Overview of the Resource--Today and Yesterday

R. C. Kellison, Hardwood Research Cooperative, North Carolina State University, Raleigh, NC

M. Young, Hardwood Research Cooperative, North Carolina State University, Raleigh, NC

Between 1962 and 1986 the use of hardwoods in the South increased from 1,715 to 2,940 million cubic feet. The increase, almost all from private lands, was primarily used for fuel (38%) and for the manufacture of pulp, paper and paperboard. This resource, much of which has been obtained from wetlands, is available from a shrinking land base. According to Dahl (1990), the southern wetland forest base shrunk from 112 million acres in 1780 to 57 million acres in 1980. Of the 1980 total, 42 million acres were in private ownership. That ownership class was extremely vulnerable to conversion from forest to field in the 1970s and 1980s when the price of agricultural crops (soybeans and corn) reached an all-time high. The reduction in acreage of wetlands from 1980 to 1987 on non-federal lands was from 42 to 29 million acres. Despite these startling figures, evidence shows that the bottomland hardwood resource was at a lower ebb during the half century following the Civil War than it is today.

Development and Ecology of Bottomland Hardwood Sites

J. D. Hodges, Department of Forestry, Mississippi State University, Starkville, MS

A basic knowledge of the origin, development, and ecology of bottomland hardwood sites is important for assessing harvesting impacts on these sites. This paper will give an overview of the geologic origin and development of hardwood sites, species-site relationships and the natural patterns of ecological succession on these sites, and the implications of this information for forest management.

Past geologic events led to the formation of broad stream valleys within the Coastal Plain Province of the Atlantic Plain Physiographic Division. Formation of these valleys was possible because of the easily erodible sedimentary geologic material. The valleys contain an active floodplain and at least one terrace system. Bottomland hardwoods occur primarily on the floodplains of these stream valleys.

Elevational differences within the active floodplain occur due to bank overflow and meandering of the stream across the floodplain. Small differences in elevation can result in great differences in site quality primarily because of differences in hydrology. Species occurrence and natural patterns of ecological succession within the floodplain are strongly influenced by these differences in elevation and rates of deposition.

Silvicultural Systems for Southern Bottomland Hardwood Forests

J. S. Meadows, USDA Forest Service, Southern Hardwoods Laboratory, Stoneville, MS

J. A. Stanturf, USDA Forest Service, Southern Hardwoods Laboratory, Stoneville, MS

Silvicultural systems integrate both regeneration and intermediate operations in an orderly process for managing forest stands. Silvicultural practices are traditionally divided into two systems: even-aged and uneven-aged. The regeneration methods employed under even-aged silviculture include clearcutting, seed tree, and shelterwood. Single-tree selection and group selection are regeneration methods used under uneven-aged silviculture. Artificial regeneration can be used to establish new stands through plantation culture or to supplement natural regeneration through enrichment planting.

The clearcutting method of regeneration, because it provides ample sunlight to the forest floor, favors the development of moderately intolerant to intolerant species. In fact, clearcutting is the most proven and the most widely used method of successfully regenerating bottomland oak species in the South. However, successful regeneration of oak depends upon the presence of adequate oak advance reproduction in the stand prior to clearcutting. The seed-tree method of regeneration favors the establishment of light-seeded species, such as sweetgum and yellow-poplar. Site preparation may be necessary if the desired species requires bare mineral soil for establishment, as for cottonwood and black willow. The shelterwood method of regeneration favors the development of heavy-seeded species, such as oaks and hickories, and has been used to successfully regenerate oak in the southern Appalachians. However, it has produced highly variable results with southern bottomland oak species. Several variations and modifications of the classical shelterwood method have been attempted in these stands, with mixed success.

The single-tree selection method of regeneration favors the development of shade-tolerant species. However, there are few commercially valuable shade-tolerant species in southern bottomland hardwood forests. In fact, when single-tree selection is applied continually to stands containing commercially valuable shade-intolerant species, such as most bottomland oaks, composition will gradually shift to more tolerant species, such as sugarberry, elms, maples, hickories, and boxelder. Consequently, the single-tree selection method of regeneration is not recommended for bottomland oaks.

Group selection, in the classical sense, creates only small openings (0.04 to 0.2 ha) that usually fail to allow sufficient light to the forest floor for satisfactory establishment and development of shade-intolerant bottomland species. In practice, a combination of uneven-aged (group selection) and even-aged (clearcutting) silviculture has been successfully employed. Known as patch cutting, larger groups of up to 1.2 ha are removed at a time. The result of patch cutting is an uneven-aged stand that consists of many small, irregularly shaped, even-aged groups.

The primary artificial regeneration methods used in southern bottomland hardwoods are planting and direct-seeding (for heavy-seeded species, such as oaks), both of which can be accomplished by hand or by machine. General guidelines for artificial regeneration of bottomland hardwoods include (1) match the species to the site; (2) prepare the site; (3) use vigorous planting stock or sound seed; (4) plant or direct-seed properly; and (5) practice weed control sparingly.

Silvicultural systems should include a planned program of intermediate operations designed to enhance the growth and development of those species favored during the regeneration process. Intermediate operations can include improvement cutting, thinning, or other partial cuttings. Improvement cuttings are generally applied to previously unmanaged bottomland hardwood stands to remove low-value, overmature, damaged, or cull trees and trees of undesirable species. Commercial thinning is increasingly common in southern bottomland hardwood forests. General guidelines for thinning in bottomland hardwood stands include (1) begin thinning early in the life of the stand; (2) favor the largest trees with well-developed crowns; (3) thin from below whenever possible to remove trees with inferior crowns;

(4) use frequent, light thinnings instead of infrequent, heavy thinnings; and (5) avoid excessive logging damage to residual trees. Other partial cuttings employed today in bottomland hardwood forests typically involve some form of crop-tree release, in which individual crop trees are selected early in the life of the stand and are periodically released from competition to promote maximum growth and quality development on those trees.

Specific recommendations for the selection of silvicultural systems will be presented for the eight most important species groups found in southern bottomland hardwood forests: cottonwood; black willow; cypress-tupelo; elm-sycamore-pecan-sugarberry; elm-ash-sugarberry; sweetgum-red oak; red oaks-white oaks-mixed species; and overcup oak-bitter pecan.

Fish Reproduction in Bottomland Hardwood Wetlands of the Lower Mississippi River Basin

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G. L. Miller, University of Mississippi, University, MS

J. J. Hoover, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

Bottomland hardwood wetlands are conspicuous features of many river systems in the lower Mississippi River basin. They occur on alluvial floodplains that are inundated in winter and spring. These forested wetlands are highly productive and support diverse aquatic communities. Despite their importance to riverine ecosystems, extensive tracts of bottomland hardwoods continue to be cleared, especially from those lands bordering the Mississippi River and its tributaries. Deforestation has become a major issue in the preservation of biodiversity, but the interrelationships of forested and non-forested wetlands to biotic processes in rivers are poorly understood. Consequently, strategies to conserve and manage these environments are not well developed.

Between 75 and 100 species of fish complete one or more of their life stages (i.e., egg, larvae, juvenile, adult) in bottomland hardwood wetlands. Field surveys of larval fishes conducted in the Yazoo River System, Mississippi and Cache River System, Arkansas have shown that major groups of fishes that exploit bottomland hardwood wetlands include gars, minnows and shiners, suckers, catfishes, sunfishes, and darters. Some fishes migrate to riverine floodplains in spring to spawn on inundated vegetation, on leaf litter, or near woody debris. The larvae often remain on the floodplain for extended periods feeding on plankton. Other species spawn in the seasonally inundated floodplain and then reside as adults in the more permanent floodplain habitats throughout the year.

There is a temporal trend in the appearance of larval fish species in the wetland that is usually associated with onset, duration, and magnitude of flooding. Early spawners include suckers, crappie, and most darters. Species that spawn in late spring and early summer include catfishes, gar, minnows and shiners, and sunfishes. Minnows, shiners, and sunfishes may continue to spawn throughout the summer if suitable habitat is available in the wetland. Other species, such as buffalo and flathead catfish, have a more punctuated spawning strategy. Their larvae appear for only short time and usually in high abundance.

Regularly flooded stream systems in the lower Mississippi River basin typically include six distinct floodplain habitats, each of which can be delineated from satellite imagery or low-altitude aerial photography: 1) cultivated agricultural land, 2) fallow land, 3) floodplain ponds, 4) oxbow lakes, 5) an aggregate type consisting of scatters, brakes, and mouths of tributaries, and 6) bottomland hardwood.

(1) Cultivated Agricultural Land - These are converted forested wetlands that have been planted with crops such as soybeans, cotton, and rice. Agricultural land is structurally homogenous with little herbaceous or woody vegetation. Many of the fields occur in low-lying areas due to extensive tilling and subsequent erosion. Thus, water tends to collect and remain in these areas for extended periods. Whether adult fish deposit eggs in agricultural fields is unknown, but high numbers of larval buffalo, shad, and sunfishes are collected in this habitat.

(2) Fallow Land - These lands were previously planted with crops but were allowed to remain uncultivated to increase their productivity. Early succession herbaceous vegetation is commonly found in fallow land. Depending on the time the land remains uncultivated, willow trees and hardwood seedlings also occur. Herbaceous vegetation is a preferred spawning substrate for buffalo, gar, and some species of minnows and darters.

(3) Floodplain Ponds - Floodplain ponds are depressions or low points in the floodplain. The major difference between floodplain ponds and oxbow lakes is size; ponds are often less than 500 m^2 in surface area. They usually retain water year-around, but some become extremely shallow during the summer and fall. Consequently, high water temperatures and low dissolved oxygen are characteristic of floodplain ponds during low-water periods. Floodplain ponds support a distinct fish community that includes some of the rarest fishes of bottomland hardwood wetlands such as fliers, taillight shiners, and various species of topminnows and darters.

(4) Oxbow Lakes - Oxbow lakes are meander loops of former river channels that have been cutoff. They can be permanently connected, seasonally contiguous, or permanently isolated from the main river. The shoreline is typically wooded and brush is abundant in the water near shore. Oxbow lakes retain water year-around. Oxbow lakes that are contiguous with the river are inhabited by typical riverine species such as gar, buffalo, paddlefish, and other large species. Oxbow lakes that are isolated from the river are less turbid and piscivorous fish, such as gar, are lower in abundance. Consequently, isolated oxbow lakes are inhabited by more sunfishes, including largemouth bass.

(5) Scatters, Brakes, Sloughs, and Tributary Mouths - These are long, narrow waterbodies that are usually confluent with the main channel. They are permanent aquatic habitats that rarely become dewatered. Their distinguishing feature in remote sensing is that are dominated by cypress-tupelo trees. Unlike oxbow lakes where cypress-tupelo are usually confined to the periphery of the waterbody, cypress-tupelo trees are found throughout the surface area of scatters, brakes, sloughs, or tributary mouths. These habitats often drain interior lands, are subjected to high flows during floods, and are inhabited by a mixture of fish species from the other habitats. They also serve as corridors for movement between the parent stream and other wetland aquatic habitats.

(6) Bottomland Hardwoods - Hardwood forests border alluvial river systems and are seasonally inundated. Frequently flooded hardwoods consist primarily of cypress-tupelo trees with little understory. Infrequently flooded forest are comprised of oak-hickory complexes and often have structurally complex understories. Most are second-growth forests. Agricultural and fallow land were once hardwoods forests converted to crop land. Historically, bottomland hardwoods were the main component of riverine floodplains and provided habitat for those fish that require shallow, structurally-complex areas for deposition of eggs. These include buffalo, gar, and different species of minnows, shiners, and darters.

Management of wetlands encompasses three options: protection of existing habitat; creation of new wetland habitat; or restoration of degraded habitat. General guidelines for management of wetland aquatic habitats are relatively simple to formulate theoretically: the abundance and spatial distribution of the habitats should resemble those of productive, faunally diverse, undisturbed sites to the maximum extent possible. Practical solutions for managing wetlands include re-foresting agricultural land that is frequently flooded, converting agricultural land to fallow fields that are periodically inundated, and ensuring that permanent waterbodies on the floodplain are contiguous with the river during floods. Accessibility between river and floodplain and structural heterogeneity of floodplain habitats are two of the most important considerations for maintaining suitable reproductive habitat for fishes in the lower Mississippi River basin.

Harvesting Impacts on Soils and Nutrient Cycling

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W. H. Conner, Belle W. Baruch Forest Science Institute, Georgetown, SC

Evaluation of reports on the impact of harvesting on nutrient properties of soils indicate variable responses ranging from no effect at all to pronounced reductions in growth by successional stands. With this complex range in observations we will try to present a rationale for the nature of these findings and ideas for predicting impacts on sites for future harvesting. Harvesting impacts on site nutrient supplies and availability can be addressed from two approaches. The first represents the losses of nutrients from a site through erosion, overflow, or harvesting. The second concerns availability of nutrients and chemical alteration of nutrients in the soil and forest floor.

The removal of biomass, primarily the stem, is not considered to be a significant drain on nutrient pools for bottomland hardwoods since most of the nutrients are in foliage and soil. Normal stem-only harvest removes nutrients from the forest ecosystem at rates compatible with nutrient inputs. Where short rotations or total harvest of the tree is undertaken, changes in nutrient supplies are small enough to allow for correction of mineral nutrition through fertilization.

Harvesting effects on nutrient availability are more significant where harvesting changes the physical environment of the site. This alters biological activity, coupled with changes in nutrient cycling and "intensity" factors such as pH, redox potential, and gas partial pressures. The two physical properties with documented changes due to harvesting are temperature and alteration of the soil water table. These changes take place regardless of the direct impact of harvesting equipment, road construction or other disturbance of the site by harvesting. In general, greater site disturbance causes greater change in the physical nature of the site.

Change in soil temperature occurs regardless of drainage. With the removal of the overstory vegetation, soil temperature will be measurably higher regardless of the harvesting equipment employed. An increase in soil temperature will accelerate biological processes which release nutrients. At the same time, an increase in temperature decreases the solubility of gasses in the soil solution. This lowers the amount of carbon dioxide in the soil on drained sites which results in an increase in soil pH. Depending upon the nature of a specific site, this may increase or decrease nutrient availability. Higher temperature will accelerate the soil reduction process through greater biological activity.

The loss of evapotranspiration following tree harvest can significantly raise the water table sufficiently to saturate the surface soil or at least extend the period of surface saturation. This condition causes a loss of soil oxygen which in itself decreases nutrient availability through restricted root respiration. The flooding and soil reduction further alters nutrient availability through soil reduction where microorganisms use mineral oxides in the soil as a source of oxident.

Harvesting can indirectly alter nutrient status of a wet forest site. This takes place through changes in the physical environment that alters biological processes. Impacts of harvesting effects on nutrient availability can best be controlled by limiting disturbance of the site through planning of the harvest operation and the selection of favorable soil moisture conditions. In some cases, application of fertilizer can be used as a remedial treatment. Knowledge of soil properties and growth limiting factors of the site are needed to predict harvesting effects on site nutrient properties.

Harvesting Systems and Concepts for Wet Sites

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Environmentally acceptable and economical forest operations for sustainable management of forest resources are needed for bottomland hardwood forests. Such operations; i.e., techniques and technologies for roading, site preparing, harvesting, and transporting, are especially needed to perform forest management activities on wet sites. As the demand for hardwood resources continues to increase, improved and alternative forest operations are needed to ensure acceptance of harvesting on wet sites, typical of bottomland hardwoods.

Some alternative technologies and techniques include wide tires, fell-top-pile feller-bunchers, clam-bunk skidding, two-stage hauling, towed vehicles, cut-to-length systems, mats, helicopters, large forwarders, and cable systems. These concepts have the potential to improve system performance and reduce impacts in conventional operations and on difficult sites such as wet areas. Although many of these new alternatives are operational, some are just concepts or evolving prototypes. More research is still needed to optimize these alternative technologies and reduce costs associated with their implementation.

Impacts on Landscape Diversity

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Forest management activities potentially influence ecosystems at many spatial scales. For most forest systems, influences at the stand level have been most intensively studied and are best understood. Management impacts at the larger, landscape scale are poorly understood and many hypotheses regarding landscape effects remain untested. This lack of knowledge is particularly acute in bottomland hardwood forest ecosystems. This paper will provide an overview of prominent theories regarding landscape-scale impacts of forest management and will identify research opportunities for testing those theories.

Most hypotheses regarding landscape-level impacts were derived from island biogeography and related disciplines. Landscape theory has primarily focused on the concept of fragmentation and the consequences of breaking habitats presumed to have once been uniform into islands or isolated patches. Species presence and productivity in patches is sometimes viewed as a function of patch characteristics (e.g., size, shape, amount of edge); degree of isolation from larger, similar habitats; time since isolation; extinction rates; and immigration rates. Landscape theorists have largely been concerned about older successional stages. The effective size of older forest patches are thought by many to be reduced by changes in solar radiation, wind patterns, and water fluxes along edges where timber harvesting has occurred. Thus, habitat for species dependent upon conditions common to interior forests may be reduced. Many conservation biologists also seek to minimize high-contrast edge because of potentially high rates of predation and parasitism of bird nests associated with these habitats.

Corridors sometimes are promoted to encourage movements between otherwise isolated patches of older forest. Wildlife species are presumed by many theorists to reside as metapopulations within fragmented landscapes, generally exchanging individuals and genetic material along connecting corridors. The rate of interchange, however, is hypothesized to be less frequent than if fragmentation had not occurred. While many of these theories are intuitively sound, there are few data to demonstrate their applicability to managed forest systems, particularly bottomland hardwood forests. And, much theory is directed at designating reserves rather than improving our ability to manage forests while also maintaining biological diversity.

Most bottomland forests have been altered since settlement, thus pristine reserves generally are not feasible. Therefore, we suggest that high priority be given to using adaptive management to simultaneously test hypotheses about how biotic communities function in managed, bottomland hardwood landscapes. Such information would help managers understand the consequences of their activities, provide them with more flexibility, and improve their ability to protect biological diversity while also meeting society's needs for forest resources.

Recovery Status of a Baldcypress-tupelo Wetland Eight Years After Harvesting

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Harvesting of timber in a forested wetland has the potential to alter the wetland functional status through impacts on soil properties, hydrologic dynamics, and plant communities. Research documenting functional changes in response to wetland harvesting has often been limited to initial-response time frames of one or two years following treatment. Because of the dynamic nature of floodplain wetland systems, initial impacts to soil properties and hydrologic dynamics may be mitigated by relatively frequent flooding-drying cycles and by rapid natural revegetation.

This research is being conducted to evaluate the recovery status of a baldcypress-tupelo wetland eight years after harvesting. The effects of three harvesting treatments are being tested: (1) clearfelling with chainsaws followed by helicopter extraction of logs; (2) clearfelling with chainsaws followed by helicopter extraction and glyphosate herbicide application; (3) clearfelling with chainsaws followed by skidder simulation of log removal. The glyphosate treatment was implemented to investigate the role of vegetation in the recovery of the wetland. An undisturbed area of baldcypress-tupelo forest adjacent to the treated area serves as a reference area of age 78 years. The variables used to assess the functional status of the wetland include soil temperature, soil pH, soil oxidation-reduction potential, water table depth, woody regeneration, total aboveground biomass, and sediment deposition.

The study design is a 3x3 Latin square replicated three times for a total of 27 treatment plots. Each plot is 0.36 hectares. The reference area is a pseudo-replicated square of 9 plots. Two 1-meter deep wells for measuring water table depth and a soil sampling station for measuring soil temperature, pH, and redox potential with a portable meter at 10 cm and 40 cm are located within each treatment plot. There are two soil sampling stations in the skidder plots, one within a skidder trail and one adjacent to the skidder trail. Woody regeneration for trees > 5.0 cm dbh was measured in one 0.12-ha sub-plot and regeneration for trees < 5.0 cm dbh was measured in one 0.04-ha sub-plot within each treatment plot. Herbaceous biomass estimates were acquired from four 1 m x 1 m sub-plots within each treatment plot.

Periodic measurements of soil properties, water table depths, and vegetative regrowth were initiated in June 1993. Sediment deposition was measured using nine erosion/deposition stakes systematically located in each plot immediately after harvesting. Data for the treatments were analyzed by Latin square analysis of variance according to date and, for soil properties, depth. Each treatment was then compared to the reference value for that date using a protected LSD. Preliminary results from four sampling dates during the summer and early fall of 1993 show that soil temperature at 10 cm was higher in the glyphosate-treated plots than the other treatments. The glyphosate plots have the least woody overstory and probably receive the most direct solar radiation when compared with the other treatments. In contrast, the reference area tended to have lower soil temperature at the 10 cm depth. Redox potential varied over time, indicating a general drying trend over the course of the growing season, but it was not significantly different among treatments. Soil acidity levels followed redox potential trends. As redox potential levels increased, pH decreased, but was not consistently altered by treatments. Water table depth was significantly closer to the surface in the reference area than the treatment areas in July, August, and September 1993, suggesting that evapotranspiration rates may have been higher in the treatment areas. During October 1993 through January 1994, the site was flooded and there were no treatment effects on water depth.

Sediment removal was dependent on the amount of herbaceous biomass. The undisturbed reference area had the least herbaceous biomass and the least sediment deposition (average deposition=0.5 cm yr^{-1}). The helicopter and skidder treatments had a denser herbaceous component and abundant regeneration of water tupelo (*Nyssa aquatica*) and baldcypress (*Taxodium distichum*). These areas trapped sediment at a rate of 1.5 cm yr^{-1}. The glyphosate-treated plots had the most herbaceous biomass, sparse woody regeneration of predominately black willow (*Salix nigra*), and trapped 2.0 cm yr^{-1} of sediment.

Sampling will continue through another growing season in this ongoing study. These preliminary results indicate some level of recovery in several key wetland soil properties and in the regeneration of plant communities within the areas subjected to helicopter logging and skidder logging.

Influence of Harvesting on Water Quality, Hydrology, Denitrification, Decomposition, Amphibian Populations, Microbial Ecology, and Regeneration in Narrow Floodplains of Blackwater Streams in Southern Alabama

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The effects of two harvesting systems (handfell/helicopter and feller-buncher/skidder) on water quality, denitrification, and decomposition were investigated in southern Alabama. The research site consists of narrow floodplains of low-order, blackwater streams. These sites are dominated by Histosols and are very P deficient. On each of the three floodplains, two harvesting treatments and an undisturbed treatment were installed during March 1991. The three floodplains served as replicates in a randomized complete block design.

Composite surface water samples were collected one week per month to assess the influence of harvests on water characteristics. Surface water samples were analyzed for NO_3, PO_4, SO_4, TSS (total suspended solids), TDS (total dissolved solids), and BOD. Nitrate and phosphate concentrations were low with no apparent harvest effects during first and second growing seasons. Although harvested areas had higher TSS than undisturbed plots, sediment showed no statistical difference. Monthly BOD (biological oxygen demand) samples showed no statistically significant harvest effects, although BOD did increase slightly in harvest zones. High numerical increases in BOD values were observed in one floodplain that exhibited slow flow rates.

Groundwater wells were installed at 15-m intervals along six lines perpendicular to the floodplain (one in upstream unharvested, two in harvested zone, and three in downstream and unharvested). The bimonthly depth-to-water table was recorded, and water was pumped for NO_3, PO_4, SO_4, and Cl analysis. Drier conditions were observed following the harvest as indicated by an increase in Cl concentrations in harvested zones, depth of oxidation (averaging 11 cm in undisturbed and 17 cm in harvested zones), and water table depths (averaging 0.2 m in undisturbed and 0.4 m in harvested zones).

The acetylene inhibition technique and intact soil cores were used to measure denitrification rates. Denitrification showed a seasonal trend and within-site variation ranging from 7 to 20 kg per hectare per year, with no treatment showing consistent high or low denitrification rates throughout the study. Harvesting treatments did not significantly affect mass loss in decomposing litter, but did stimulate N and P mineralization from litter. Microsite variation affected decomposition k values and influenced nutrient availability (P availability greater in concave areas, mineral N greater on convex areas).

Two of the floodplains were surveyed for amphibians using pit traps. Harvesting, hydrologic regime, individual site variation, and temperature affected numbers and types of amphibians captured. Significant decreases in populations of fungi (*Trichodera* spp.) active in the decomposition processes were observed following timber harvest, in the order of undisturbed control greater than minimum and maximum disturbance treatment. Maximum disturbance harvesting led to a significant increase in algal and cyanobacterial biomass within treatment plots, potentially influencing soil nutrient status via nitrogen fixation, photosynthetic activity, or immobilization.

Aboveground vegetation production was significantly lower with conventional logging in the first year, but differences decreased by the second growing season after treatment. The primary mode of regeneration for some species shifted from sprouts in the helicopter treatment to seedlings in the simulated conventional treatment.

The Effects of Timber Harvest on the Functioning of a South Carolina Blackwater Swamp

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Bottomland hardwood ecosystems are important in both commercial and functional terms. This study was designed to document the impacts of forest management on the vegetation, soil and water quality, and herpetofaunal populations in a Blackwater swamp. Operational harvest treatments commonly used in the Southeast to extract bottomland hardwood timber were selected to represent a spectrum of site disturbance intensity. Treatment were installed between January 1991 and November 1991 and included: 1) simulated skidder forwarding, representing the highest level of harvesting impact, 2) helicopter forwarding, representing the lowest intensity of harvesting impact, and 3) a well-documented undisturbed stand serving as a reference for the harvest treatments.

Biomass and species richness were greater on the helicopter and skidder treatments than on the control. The herbaceous biomass measured on the skidder treatment was not significantly different than the biomass on the helicopter treatment. Despite the greater number of species present on the two harvest treatments, overall species diversity was greatest on the control. This is believed to be the result of the evenness of the biomass distribution among the species present on each treatment. Skidder forwarding does not appear to be more detrimental than helicopter forwarding on this site.

Cotton strip assay showed that organic matter decomposition increased with greater site disturbance. This response is mainly attributed to increasing soil temperatures as disturbance increased, with the overall effect being ameliorated by saturated conditions. Greater nutrient concentrations were found in shallow ground water samples from the more disturbed treatments due to accelerated decomposition. Harvest treatments filtered greater amounts of sediment from the surface water column due to the enhanced surface roughness in the harvest areas caused by thick herbaceous regrowth and logging debris. Neither pre- nor post-harvest bulk density values exhibited significant treatment differences. The deviation from the traditional changes in bulk density due to harvest impact may be attributed to the fact that the hydroperiod on the site was much longer than is typical of a blackwater river system, with over 50% of the site being flooded for approximately 88% of the monitored days after the harvest treatments were fully installed.

Thirty-one species of herpetofauna were detected on the site (11 amphibians and 20 reptiles among 5900 individuals). The 10 ha clearcut was compared to an adjacent control stand. Diversity did not differ among habitats, except that the edge had a lower diversity than the clearcut and control. Salamanders were 25 times more abundant in the control than in the clearcut. Reptiles, especially lizards and large snakes, were more abundant in the clearcut. Ruts formed by logging machinery provided breeding habitat for frogs. Two treefrog species present on the site, green and gray treefrogs, showed preference for the clearcut and the control, respectively.

Initial Responses of Vegetation, Water Quality, and Soils to Harvesting Intensity in a Texas Bottomland Hardwood Ecosystem

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A riparian bottomland hardwood ecosystem in Texas was chosen to test the effects of standard forest harvesting practices on aspects of vegetation, water quality, and soils. The study was located in the Neches River floodplain (Tyler County). Soils are varied but are predominantly acid, thermic Aeric Fluvaquents (Ozias and Pophers series) and siliceous, thermic Fluvaquentic Dystrochrepts (Laneville and Iulus series). The study area was heavily logged in the early 1920's, but was largely undisturbed since then. The overstory was principally sweetgum (*Liquidambar styraciflua*) and water oak (*Quercus nigra*) while the midstory was heavily predominated by ironwood (*Carpinus caroliniana*). Clearcutting (CC), partial cutting (PC, approximate halving of basal area), and a non-cut control (CT) were tested on 8.1-ha square plots located along minor drainages within the floodplain. Three replications were established such that the drainages approximately bisected the plots, and treatments were arranged in downstream order as CT, PC, CC. Streamside management zones extending about 20 m from each stream bank were left either undisturbed or were occasionally selectively harvested. Mechanical harvesting occurred in September 1992, during dry conditions. No post-harvest site preparation was performed.

The woody vegetation community was sampled immediately before and about one year after harvesting. The objectives of this research were to monitor regeneration dynamics after harvesting and to test the hypothesis that early post-harvest regeneration cannot be readily predicted from pre-harvest composition. Nine permanent subplots were systematically established in each treatment plot, each subplot consisting of three concentric plots: a 0.004-ha plot for understory vegetation, a 0.02-ha plot for midstory vegetation, and a 0.08-ha plot for overstory vegetation. Calculation of importance values and diversity indices as well as ordination by detrended correspondence analysis (DECORANA) indicated no substantial changes one year after harvesting in regeneration composition. However, regeneration composition is expected to change rapidly in the early years of stand development so annual surveys will continue.

Streamwater and subsurface water quality were monitored in the streams and in water wells, respectively, to determine if harvesting and subsequent accelerated leaching, decomposition or mineralization resulted in measurable water quality changes. Nine 2-m wells were systematically installed two months before harvesting in each treatment plot for monthly monitoring of water table depth and subsurface water quality. Water temperature, pH, electrical conductivity, and dissolved oxygen concentration were measured directly in the wells with a portable analyzer after bailing and recharge. Subsurface water samples were also analyzed for inorganic nitrogen and phosphorus colorimetrically with an autoanalyzer. Streamwater was sampled at permanent grab-sampling stations located at plot borders. Streamwater quality was measured by the same techniques as those for subsurface water, with the addition of turbidity measured since May 1992, with a portable turbidity meter.

Results for subsurface water indicate that dissolved oxygen, temperature, pH, electrical conductivity, and concentrations of ammonium and phosphate were not altered significantly during the first 16 months after harvest. Ammonium-N and phosphate-P concentrations were consistently less than 0.7 and 0.1 mg L^{-1}, respectively. Dissolved oxygen and temperature showed strong seasonal trends with low temperature and high oxygen in the winter and high temperature and low oxygen in the summer. Clearcutting significantly ($\alpha = 0.05$) increased nitrate-N in subsurface water four and five months after harvesting. Four-month concentrations were 0.14, 0.58, and 1.29 mg L^{-1} for the CT, PC, and CC, respectively; five-month values were

0.13, 0.14, and 0.48 mg L^{-1}. Average values during 16 months following harvesting were 0.06, 0.19, and 0.64 mg L^{-1} for the CT, PC, and CC, respectively. During 16 months following harvesting, the average monthly water tables in the CT, PC, and CC were 110, 95, and 94 cm below the surface, respectively. Pre-harvest water table depths were approximately equal. Pre-harvest streamwater quality was consistent among sampling stations within each stream. Streamwater quality has not been affected by harvesting. Monitoring will continue to determine if trends are short-lived.

Soil physical properties were monitored to test the hypothesis that impacts reflect the degree of harvest trafficking, and that degree of impact would decrease in the order CC > PC > CT. Soil sampling was conducted from May through August 1993. One hundred 5-cm x 5-cm intact cores were systematically collected at 0-5 and 5-10 cm depths in each treatment plot. Preliminary results indicate that bulk density across both sampling depths was 4.3% higher in the CC than in the CT. This difference was related to a 34% relative decrease in macroporosity across both sampling depths in the CC. Although not significant ($\alpha = 0.05$), saturated hydraulic conductivity and total porosity were also lowest in the CC. Soils in the PC had intermediate levels of bulk density, microporosity and saturated hydraulic conductivity.
These early results suggest a gradient of increasing impacts with increasing trafficking on a treatment area basis. Additional analyses on data separated by soil texture and disturbance class within treatment plots are being evaluated to determine more specific responses to treatments.

Disturbance and exposure of mineral soil and the increase in litter from logging slash following harvesting may result in increased soil heterotrophic microbial activity. The hypothesis that degree of stand removal is directly related to subsequent soil microbial activity was tested by measuring respiration rates both *in situ* and in laboratory incubations. Eight sampling points were located in each treatment plot on a common soil series (Ozias) at which soil CO_2 efflux was measured for 24 hours with the soda lime absorption technique, and soils were sampled for ten-day laboratory incubations using a modified version of the wet alkali method. Soil temperatures were measured prior to *in situ* incubation, and soil moisture was determined gravimetrically prior to lab incubation. Lab incubation was performed at field soil temperatures. Sampling was done approximately monthly as site conditions permitted. Results to date indicate no mean significant ($\alpha = 0.05$) treatment effect on either *in situ* or laboratory soil respiration rates. However, individual sampling periods showed efflux rates significantly ($\alpha = 0.05$) higher in the CC than in the PC and CT, or no difference between the CC and PC when both were higher than the CT. Efflux rate, soil temperature, and soil moisture content generally decreased in the order CC > PC > CT. Both soil temperature and soil moisture were related to rates of field CO_2 efflux. Rates will continue to be monitored to determine if vegetation regrowth affects these processes.

Overall, these analyses show a minimal alteration of wetland functions resulting from the harvest treatments. However, monitoring will continue in order to determine the temporal nature of all measured processes as vegetation becomes reestablished.

Road Construction and Harvesting Impacts on Functions of a Redwater Floodplain Forest in Central Georgia

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The effects of road construction and silvicultural systems are being evaluated in terms of their effects on biogeochemistry, regeneration, and sediment deposition on the Flint River floodplain. The research site is composed of three replications (two located in well-drained high-flats and one in a frequently flooded low-flat) with three 8.1-ha treatment plots (clearcut, deferment cut, and an undisturbed control) located on each replicate. Treatments were installed in September 1993. Twelve shallow water wells (1.2 m below ground surface), two deep water wells (2.4 m below ground surface), two automated water samplers (one 30 m north of the northern plot boundary, and one 30 m north of the southern plot boundary), twelve 2.4-m crest gages, 12 welding rods, twenty 1.8-m radius regeneration plots, and twenty 0.5-m^2 feldspar clay marker horizons were established on each treatment plot.

Depth-to-water table, dissolved oxygen, and temperature of groundwater is recorded in each of the groundwater wells. Surface water samples collected by automated composite water samples during each flooding event will be analyzed for organic and inorganic forms of nutrients in order to assess changes in biogeochemical transformation functions. Crest gages were used to record the highest level of floodwaters and will be evaluated on a flood event basis. Cores from feldspar clay marker horizons will be used to measure sediment deposition over discrete periods of time. Depth of oxidation will be examined on each treatment plot after flooding seasons. Preharvest and postharvest regeneration surveys were conducted. All seedlings and saplings were inventoried on the twenty 1.8-m radius plots and two 3.6-m radius plots.

Sediment deposition and generation associated with four road surfacing treatments are also being investigated. The replicated test consists of gravel, gravel with geotextile fabric, native surface with vegetative stabilization, and bare native material test sections. Sediment movement is being assessed using automated composite water samplers, erosion bags, erosion stakes, and surveyed road cross-sections. The construction and operational performance of the road test sections during harvesting will be described as well as the experimental design and installation of measurement sections.

Comparison of Productivity Values Across a Flooding Gradient in a South Carolina Coastal Plain Forest

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In floodplain forests the timing, duration and frequency of inundation affect community development and aboveground productivity. Aboveground primary productivity is greatest where 1) periodic flooding brings in organic matter and nutrients as dissolved, particulate, and sediment-absorbed forms, 2) periodic flooding provides an adequate water supply for trees to use during dry periods, and 3) the frequent draining results in an oxygenated root zone. We know that there is tremendous spatial variation in the hydroperiods of floodplain systems, however previous studies have tended to lump together transition forests as floodplain communities. We address this heterogeneity issue with our ongoing study of aboveground production -- leaf litter, mast production, and tree growth -- across a gradient that includes a hardwood and pine forest, a bottomland hardwood forest, and a tupelo swamp. This study will help determine how the primary productivity functions of wetlands are affected by differences in hydrology.

Forested Wetland Productivity: A Study of Regional Processes

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Much attention has been focused in recent years towards developing a better understanding of ecological processes in forested wetland ecosystems. While several investigators have compared structure and function of individual wetlands or wetlands within a local area (Florida, Kentucky, Virginia, or Louisiana), no one has attempted to study processes on a regional scale. This study was designed to compare the effect of hydrologic regime on tree growth in wetland forests in South Carolina (Atlantic Coastal Plain) and Louisiana (Gulf Coastal Plain). Specific objectives included 1) determining the relationship between flooding frequency and site productivity and 2) comparing the amount, duration, and pattern of diameter growth of three common wetland species (*Taxodium distichum, Nyssa aquatica,* and *Nyssa sylvatica* var. *biflora*) with respect to region and hydrologic position.

Site productivity was studied in paired 20 m x 25 m plots established to represent dry, periodically flooded, and flooded environments in three Louisiana and three South Carolina study areas. All trees greater than 10 cm diameter at breast height (dbh) in each plot were tagged and measured beginning in the fall of 1986. For two years, end of year diameter, monthly litterfall, and monthly water levels were recorded. Since 1989, annual measurements of dbh only have been made at the end of each growing season. To study species specific growth parameters, dendrometer bands were installed on trees in all three Louisiana sites in 1986 and weekly dbh changes and water levels were recorded from March to September 1987. In South Carolina, dendrometer bands were installed at five locations during the summer of 1988 and weekly changes in diameter and water levels were recorded from March through November 1989, and April through November 1990. Since weekly diameter changes were made in different years, current and previous year weather patterns were examined to make comparisons of the two regions more valid.

The degree of flooding varied considerably among plots, and a flooding depth days index was developed to provide a more accurate definition of the flooding regime of the sites. Data indicate that the Louisiana sites are wetter (flooded 3-7 months of growing season) than the South Carolina sites (flooded 0-1 month of growing season). In our measurements of litterfall and woody productivity, leaf production was fairly consistent for both years within a plot, but wood production was highly variable. Wood production increased an average of 173 g/m^2 from 1987 to 1988 in South Carolina, but dropped 86 g/m^2 in Louisiana. Since trees tend to allocate carbon resources to leaves and roots first, we would expect litterfall values to be more consistent from year to year. Woody biomass changes seem to be better indicators of differences among areas.

In the second part of this project, we found few differences in mean annual growth, growth phase length, and growth curve shape between regional populations of the three studied species. In general, annual variations in these parameters were greater than differences among locations. Differences in hydrologic regime, however, were shown to have significant effects on all parameters for mature trees. *Nyssa sylvatica* var. *biflora* was restricted to periodically flooded sites in both regions and showed little response to differences in mean water depth. Significant differences among hydrologic regimes were detected for *N. sylvatica* in both regions, but in Louisiana, no obvious pattern of growth response was detected across the gradient of hydrologic regimes. In South Carolina, maximum growth of *N. aquatica* trees was inversely related to mean growing season water levels. Maximum growth of *T. distichum* was observed at sites with shallow, permanent flooding in both regions.

Bottomland Hardwood Forest Management and Information Needs for Watershed Planning

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There is a rich history of cooperative research on bottomland hardwood forests in the South. Much of the past research has focused on silviculture, and substantial progress has been made. Silvicultural research will continue to be important and should not be neglected. Management of these ecologically rich forests faces new challenges today, however. There are many other questions that must be addressed to support the goal of managing bottomlands for timber, while maintaining ecological functions that society values.

Federal and state agencies charged to protect water quality are reorganizing their programs to identify watersheds as the basic unit of organization. There is increasing interest in using watershed planning as a way of coordinating regulatory efforts between point and nonpoint sources. The Clean Water Act includes a process for this known as Total Maximum Daily Load. This process attempts to estimate the total capacity of a waterbody to assimilate pollution and then apportions the maximum amount allowable among all sources of pollution, including point and nonpoint sources as well as those resulting from natural processes. This concept is also being considered in market-based approaches for improving water quality. Point source dischargers would pay to reduce upstream nonpoint source discharges rather than decrease their own point source discharges.

There are many technical challenges to be addressed before such programs can be successful. One is a better understanding of the contribution of natural processes to nonpoint source pollution. A key step to further our understanding of natural processes is to develop models to quantify the spatially and temporally complex hydrology that characterizes bottomlands. Once that is accomplished, hydrology can be coupled with research on sediment and nutrient import/export and transformations to better predict nonpoint source pollution in undisturbed conditions, and as a managerial tool to assess consequences of forestry operations.

In general, we need a better understanding of the many ecological functions that make bottomlands so valuable to society. This presentation intends to catalyze a discussion of research needs for future management of bottomland hardwood forests. A few examples are:

- Models to quantify bottomland hydrology both spatially and temporally.
- Models to quantify sediment and nutrient processes in surface and groundwater.
- Quantify the relative contribution of plants, microorganisms, and geophysical processes in improving water quality.
- Characterize the invertebrate communities in bottomlands: species composition, diversity, spatial and temporal variability, and applicability for use as bioindicators to assess water quality.
- Quantify long-term effects of different timber management practices on ecological functions.
- Quantify soils, vegetation, and hydrology to better delineate the wetland portion of bottomlands.

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The effects of timber harvesting in bottomland hardwood ecosystems was examined at a workshop held May 18-19, 1994. Overview papers and results from studies on six river systems were presented. Directions for future research were examined.

Keywords: Bottomland hardwoods, ecosystems, forested wetlands, harvesting, regeneration, water quality.